



Exploring 3D Printing for Philippine Furniture Industry: Opportunities and Challenges

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Abstract.

The Philippine furniture industry, which is renowned for its creativity and craftsmanship, is faced with the challenge of adapting to rapidly changing consumer preferences and complexities of manufacturing. The article summarizes the potential of 3D printing to revolutionize the industry by addressing the challenges through current innovative manufacturing solutions. It evaluates appropriate materials, including polymers, metals, and sustainable alternatives such as recycled and biopolymer materials, and analyzes a variety of 3D printing technologies, including Material Extrusion, Powder Bed Fusion, and Vat Photopolymerization. The study also looks at the impact of 3D printer build volumes, ranging from desktop printers to large-scale systems like the large-format 3D printer and Hangprinter, on furniture manufacturing. Additionally, the adoption of 3D-printed connectors, hybrid designs that combine 3D-printed and conventional materials, and fully 3D-printed furniture are the other three integration strategies presented in this paper. While widespread adoption is constrained by high costs, technical challenges, and a limited selection of materials, the article suggests Philippine-specific strategies such as employing recycled materials,

hybrid production, and reasonably priced Fused Filament Fabrication (FFF) technologies. The Philippine furniture industry can position itself competitively in the global market by implementing these techniques, which will also improve design flexibility, lower costs, and increase sustainability. The findings show the revolutionary potential of 3D printing while emphasizing the significance of further research and local initiatives to overcome current limitations.

Keywords: *3D Printing, Furniture, Furniture Industry, Philippines, Strategies*

Introduction

The Philippines is referred to as the “Milan of Asia” because of hard work, creativity, and enterprising qualities of its people in making high-quality furniture. With 98% of its businesses categorized as small and medium-sized enterprises, the Philippine furniture industry employs 2.1 million indirect workers nationwide and serves 5.4 million people through its supply chain [1]. Currently, furniture is available in many styles and designs, ranging from classical and ornate to modern and minimalist, across the Philippines. This wide range aims to cater to the diverse needs and preferences of individuals, highlighting the versatility and adaptability of furniture in meeting evolving lifestyle demands. However, the constant change in consumer preferences poses a challenge to manufacturers regarding production complexity and lead times. Rapidly evolving design trends also require manufacturers to be flexible and adaptable, which is also challenging [2]. Taking these challenges into account, Additive Manufacturing (AM) commonly known as 3D Printing has been revolutionizing the product designs and manufacturing processes of several industries, including the furniture industry [3], [4], [5], [6], [7], [8]. 3D printing is making a huge impact on the furniture industry, and it is one of the latest innovative processes used in furniture manufacturing. A lot of international companies from wealthier countries are already adopting 3D printing in the prototyping and manufacturing of furniture because it provides flexibility in creating furniture with complex and intricate designs in just a few steps. In addition, the incorporation of 3D printing into artisanal products like furniture provides more material options and improves production capabilities, and systematic production practices that efficiently minimize material used and production time [9].

In the Philippines, the mainstream adoption of 3D printing is a relatively recent phenomenon. It gained significant momentum between 2019 and 2021, marked by the establishment of research facilities like the Advanced Manufacturing Center (AMCen) and Additive Manufacturing Research Laboratory (AMReL) [10]. This manufacturing process has attracted local businesses and consumers due to its ability to meet high customization demands and provide cost-efficient alternatives. 3D printing presents vast opportunities for industries by enabling rapid prototyping, reducing production costs, and supporting sustainable practices. Its potential for innovation across various sectors highlights a promising market outlook in the Philippines [11]. However, even with all these advantages and efforts from the country’s Department of Science and Technology (DOST), the Philippines is still lagging when it comes to the adoption of this process in sectors like the furniture industry. In this paper, the author will discuss various types of 3D printing technology, and materials that are currently being utilized in the field of furniture

making internationally. Different types of 3D printers based on their build volume and different approaches to integrating 3D printed parts in furniture will also be presented. The objective of this paper is to give insights into the possible adoption of the 3D printing in the Philippines' furniture industry and to give possible solutions to overcome several challenges and things that must be considered for its adoption.

Furniture 3D Printing

The 3D printing process begins with 3D modelling using Computer-Aided Design (CAD) software or 3D scanning that must be saved as STL, .OBJ, etc., which is compatible file format with slicing software, usually dedicated to a specific 3D printer. The slicing software will divide the 3D model into layers and define parameters such as printing speed, layer thickness, infill density, etc. [12], [13], [14], [15]. The slicing software converts the .STL file into G-code, which directs the printer on how the 3D object will be printed [13]. Once the G-code is transferred to the printer, the 3D object is then built layer by layer. Once the printing is done, the part will undergo post-processing before it will be used [15]. Fig. 1 shows the general process of 3D Printing.

In furniture 3D printing, various considerations must come into mind (See Fig. 2), including the type of 3D printing technology to be used, selection of 3D printing materials, the build volume of the 3D printer to be utilized, whether it is a desktop 3D printer, large format 3D printer, or frameless 3D printer, and designers approach in considering the number of parts or components to be printed, whether the piece will be fully 3D-printed, only some components will be 3D-printed, or whether only the joineries or connectors will be 3D-printed. In the following sections, the paper will present a clearer breakdown of these various considerations.

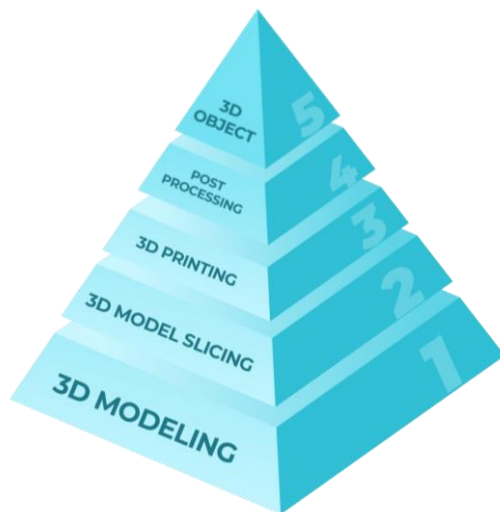


Fig. 1. General process of 3D Printing

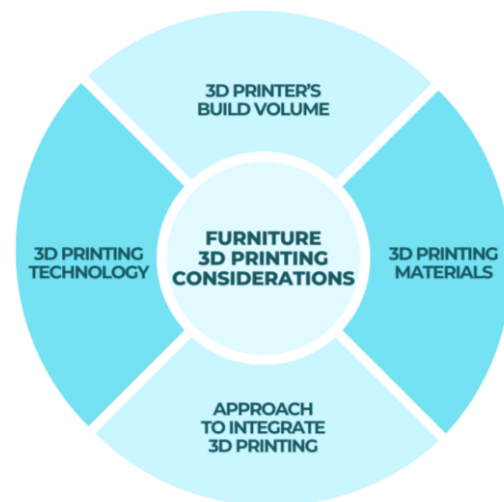


Fig. 2 Various Considerations in Furniture 3D Printing

3D Printing Technology

3D printing includes various technologies categorized into processes such as Powder Bed Fusion (PBF), Binder Jetting (BJ), Directed Energy Deposition (DED), Material Extrusion (MEX), Material Jetting (MJ), Sheet Lamination, and Vat Photopolymerization [12], [16]. Among these methods are gaining prominence in the furniture industry due to their ability to meet specific design and manufacturing needs efficiently, as highlighted by Tuazon et. al [17].

Furniture consists of movable objects designed to enhance the comfort and functionality of living or workspaces. It supports essential human activities like sitting, dining, storage, working, and sleeping. Beyond its practical uses, furniture also serves as a form of decorative art and can hold symbolic or religious significance. It is crafted from a variety of materials, such as wood, metal, and plastic, to suit diverse needs and styles. Furniture has four main classifications which include, Storage furniture like a bookshelf, wardrobe, etc., Seating furniture like a sofa, chair, etc., Surface furniture like a coffee table, table, etc., and Spaces furniture like dining table, bed, etc.[18].

Material Extrusion. Most of the 3D-printed furniture is often manufactured using a material extrusion-based technology. The most used type of this technology is the Fused Filament Fabrication (FFF) or Fused Deposition Modeling (FDM) which uses a thermoplastic filament as its printing material. In FFF/FDM, the printer prints a 3D object by extruding a molten thermoplastic material following the sliced 3D model [15], [19]. The molten material is positioned layer upon layer until the 3D object/part is created. This printing technique is relatively fast and cheap but requires support structures especially for complex shapes [15], [20]. Material extrusion-based 3D printers are not only limited to using thermoplastic polymers that come in a filament form. Recently, 3D printers have now adapted to print materials in granular or pellet form. In the past, these materials were often used for injection molding, but it has now become more popular in 3D printing because the materials in pellet form are way cheaper than in filament form, and it also allows a wider range of material options than in filament form [21].

Powder Bed Fusion. Another common 3D printing technology used in furniture applications is the Selective Laser Sintering (SLS) and Selective Laser Melting (SLM) additive manufacturing which are types of Powder Bed Fusion (PBF). The powder bed fusion process is a technology used in a product with precision [22]. The components of this printing process include the build platform, the printing chamber (including the powder bed), the powder reserve chamber (including the refilling powder), and the laser beam (source). The printing chamber and powder reserve chamber are initially heated to a certain temperature (below the melting point of the material). Then, a bed of powder is partially targeted by a laser beam to fuse the powder materials into a predefined 2D shape/contour (based on the 3D model) on the surface of the powder bed. The top surface of the powder bed is refilled with a fresh layer of powder (from the refilling powder chamber) covering the sintered cross-section. This process is repeated until the desired 3D object is accomplished. It is possible to easily print complicated shapes with SLS as this process does not need structural support since the powder bed acts as a support for the printed item[23], [24], [25]. However, SLM uses support in reinforcing small angles and hangovers of the parts, which will be removed manually after cooling [26]. SLS is known to be used for a plastic-based powder bed fusion system, while SLM is known to be used for a metal-based powder bed fusion system [27], [28].

Vat Photopolymerization. The processes mentioned earlier use filament, powder, or pellet materials. However, Stereolithography (SLA) is an additive manufacturing process wherein a part is created by selectively curing a photosensitive thermoset polymer resin (liquid) layer-by-layer using an ultraviolet (UV) laser beam [29]. The build platform is initially positioned in the vat with liquid photopolymer resin, at one layer height from the surface of the liquid resin. Then, the ultraviolet laser creates the next layer by selectively curing the resin. The laser beam follows a predetermined path based on the cross-sectional area of the 3D model. After curing a layer, the build platform moves down (in other designs moves up) and the sweeper/wiper recoats the surface with a new layer. This process is repeated until the part is complete. Post-processing may be needed to achieve optimum thermo-mechanical properties. With this technique, high resolution could be achieved that is why is widely used in the furniture industry [17], [30].

Sheet Lamination. Laminated Object Manufacturing (LOM) is a type of sheet lamination process that is widely used in the furniture industry for manufacturing furniture-like parts due to the used material[31]. During the process, layers of heat-activated sheets of materials, such as plastic foam, ceramic, or metal powder-impregnated materials, are fused and laminated together by the hot-pressing cylinder. Then the formed layers are cut into the desired shape with a computer-controlled laser. LOM is known to have a poor to average finish and the resolution is dependent on the thickness of the sheet used and the adhesion pressure [32]. Tao et al. proposed a 3D printing method for wood-based product fabrication inspired by laminated object manufacturing (LOM) and plywood technology called laser-cut veneer lamination (LcVL). Their designed LcVL-product structures could serve as material matrices for functional wood-based materials adjusting internal voids and wood-texture directionality. They also conclude that the processing resolution of LcVL and proportional veneer layer height have a direct correlation. These findings could serve as a basis for the further development of large-scale wood usage in 3D printing [33].

3D-Printing Materials

Like other manufacturing methods, furniture 3D printing relies on high-quality materials and appropriate technology that meet specific standards for consistently producing superior products. Consequently, material selection is a critical factor in 3D printing furniture. Currently, the range of materials used in this industry is limited to certain polymers, metals, and composites, as not all materials can be easily thermally controlled, which is a key requirement for effective 3D printing[34]. As reported by Tuazon et al., most 3D-printed furniture is made of polymers and metals, but some also use biopolymer materials [17]. This section will highlight 3D printing materials for furniture manufacturing that can be economically viable for the Philippines.

Polymer Materials. Acrylonitrile Butadiene Styrene (ABS) is an engineering thermoplastic polymer with a versatile property aside from being inexpensive which is why it is advantageous in a wide variety of industries, including furniture industry. It is valued for its high tensile strength, and it has good resistance to impact and chemicals, which allows the ABS 3D-printed parts to withstand heavy applications and adverse environmental conditions. It is also excellent at high and low-temperature performance. ABS has a low melting point of around 200 °C, allowing it to be used easily in 3D printing [35], [36].

Polylactic Acid (PLA) is a versatile and cost-effective bioplastic commonly used in 3D printing, like ABS. However, PLA is less durable under stress and less suitable for long-term applications than ABS. Despite these limitations, PLA is non-toxic, inexpensive, versatile, easy to print due to its lower-melting temperature, and does not require a heated bed. Thus, PLA is the most popular and default material option for FFF/FDM 3D printers. It is also one of the most environmentally friendly filaments on the market today, derived from renewable resources and is biodegradable [37], [38]. PLA has been utilized to create 3D-printed furniture pieces. It has been found in furniture that is fully 3D-printed and in furniture with 3D-printed components either seating furniture or surface furniture [17].

Polyamide has been utilized across different classifications of 3D-printed furniture. It was used in manufacturing seating, surface, and space furniture that are entirely 3D-printed, in furniture with 3D-printed components, and in furniture with 3D-printed joints [17]. Polyamide (PA) commonly known as Nylon is a synthetic thermoplastic that is an ideal selection for printing durable parts because it offers excellent tensile strength, higher impact and abrasion resistance, and flexibility, compared to ABS and PLA [39], [40], [41]. In addition, 3D-printed polyamide material usually requires less post-processing because it often has a good surface finish. However, it has a high melting point and is hygroscopic, making it difficult to use for printing [42]. These materials can be 3D-printed using material extrusion, multi-jet fusion, or powder bed fusion technology, depending on their form. Common types of polyamides frequently utilized in SLS are PA11 and PA12, as they are inexpensive and match the laser wavelength of most SLS 3D printers [43]. It was reported that the mechanical properties of laser-sintered polyamides have same elastic modulus and tensile strength of those manufactured via injection molding, but with lower elongation at break [44]. The properties of powdered polyamide can also be improved by reinforcing it with glass fiber or carbon fiber particles to produce lightweight components with excellent mechanical properties, which was also utilized in some 3D-printed furniture [45].

Aside from Polyamide, PLA, and ABS material, Photopolymer resin was also used in furniture 3D printing [17]. The photopolymer resin material provides smooth and fine finished parts with high resolution and good thermal stability due to its high crosslinking density; hence, this material is usually used in 3D printing technology, mostly in SLA 3D printing and Material Jetting (MJ) technology [46], [47]. However, photopolymer resin, such as epoxy resin, is one of the less-used materials in 3D printing, compared to other materials because it offers limited strength and flexibility [40]. Generally, resins can be developed to simulate different properties of traditional materials. For example, standard SLA resins provide highly accurate features with intricate details, high flexural strength, and a smooth surface finish, making them suitable for prototyping applications [48], [49]. Other resins like durable resins can simulate the properties of traditional thermoplastics like ABS and PP, allowing for greater strength, toughness, and durability than standard resins. These types of resins are suitable for functional prototypes and consumer products [50].

Recycled Polymer and Biopolymer Materials. The circular economy has popularized the use of recycled or indigenous materials in the 3D printing of furniture. Some furniture makers use recycled polymer materials, such as recycled PETG and recycled PP and PE plastic waste, while some use biopolymer materials, such as lignin and wood composite pellets.

Recycled Polyethylene terephthalate glycol (PETG) is made from reclaimed and sorted PETG materials which is an excellent sustainable alternative for 3D printing. In addition, PETG offers several advantages over other materials, such as ABS and PLA, in terms of ease of use, mechanical strength, and resistance to climatic agents. PETG is a strong and durable, resistant to inclement weather, easy to print filament, does not generate warping, high quality, and glossy surface finish, excellent mechanical resistance, and rigidity, and it is grateful for an adherent to the heat bed of 3D printer [51]. PETG is a type of single-use and reusable drinking bottles, which is one of the main contributors to plastic waste. Its recyclable property makes it an ideal choice for a more sustainable and durable option in manufacturing 3D-printed furniture.

Recycled polypropylene (PP) is becoming a popular choice for sustainable 3D printing [52]. 3D-printed parts from recycled PP have shown comparable mechanical properties to those made from virgin materials and can be further improved with the addition of reinforcing agents [53]. PP is tough, rigid, and resistant to fatigue failure. It is also resistant to chemical reactions from diluted bases and acids, which makes it a good recycled material option for making outdoor furniture. Although Recycled PP may have some limitations compared to virgin PP, such as reduced strength and flexibility, these can be addressed through material blending and processing optimization [54].

Recycled polyethylene (PE) plastic is a post-consumer PE waste primarily used as plastic bottles, bags, and containers. As of 2017, it was reported that over 100 million tons of PE resins are being produced annually, accounting for 34% of the total plastics market [55]. Therefore, recycling these plastics is a good idea, since most of our plastics waste can be attributed to the amount of their production. Although recycled PE filaments may have slightly different mechanical properties than virgin PE, research is ongoing to optimize the process and improve performance[56].

Aside from recycled polymer materials, biopolymer materials are also increasingly used for 3D-printed furniture due to their sustainability and versatility. Derived from renewable sources like plant starches, cellulose, and proteins, biopolymers are biodegradable, eco-friendly, and reduce reliance on petroleum-based plastics, making them ideal for sustainable manufacturing practices [57], [58]. Biopolymers can be tailored through additives and reinforcements to enhance mechanical strength, thermal stability, and durability. Biopolymer-based 3D printing holds great promise for producing eco-friendly furniture while supporting circular economy principles through recyclability and waste reduction. Advanced 3D printing techniques like FFF/FDM, SLS, and SLA have been optimized for biopolymer use, enabling the creation of complex designs with improved printability and minimal environmental impact [57]. Several biopolymers show promise for 3D-printed furniture, including biopolymers derived from lignin and cellulose. Researchers at Rice University have developed an additive-free, water-based ink made of lignin

and cellulose, the fundamental building blocks of wood. This ink can produce architecturally intricate wood structures via 3D printing, potentially revolutionizing furniture manufacturing [58]. Also, research about biopolymer production from alginate-based blends has shown that alginate blended with other materials like pea protein can create printable inks with good mechanical properties and shape retention, suitable for furniture structures. But challenges remain in scaling production due to material variability, cost considerations, and process optimization [59]. Recently, wood-filled filament is also one of the emerging materials for 3D printing furniture. Wood-filled filaments are generally made with biopolymers, combining a PLA base with wood particles, cork, or other derivatives, typically containing around 30% wood content. These filaments offer a wood-like appearance, texture, and even aroma, making them ideal for decorative and artistic applications like furniture and interior design [60], [61], [62].

Metallic Materials. Metal-based 3D printing is now highly a relevant in many manufacturing industries because it allows production of parts with almost the similar strength like of a regular metal parts [63]. Metal 3D printing offers a solution for light weighting of parts used in various industries, including furniture. Metal 3D printing is based on powder bed fusion technology that uses a powdered metal [42]. The following metals in powder forms, such as Titanium and Aluminum alloys, have already been used for the 3D printing of furniture. [17]. Although polymer materials have primarily been used for in 3D printing because it is inexpensive, attempts are being made to make metal 3D printing more affordable [64].

3D Printer's Build Volume

In manufacturing 3D-printed furniture, the build volume of a 3D printer is a crucial factor alongside printing technology and materials. Furniture makers employ three techniques based on build volume: desktop 3D printers for smaller, modular parts joined together; large-scale 3D printers capable of producing larger pieces in one print; and the innovative Hangprinting technique that allows for printing larger objects without traditional frame constraints [65].

Desktop 3D Printer. If the project requires creating smaller parts, a desktop 3D printer is the ideal option. A desktop 3D printer is a small 3D printer that can print 3D objects from raw material. Generally, desktop 3D printers are ideal for limited workspaces because they are small and compact. This 3D printer can sit on a desk, next to the computer offering a space-saving solution. Common desktop 3D printers have a smaller build volume ranging from 150 mm to 200 mm cube dimensions. It is an excellent fit for small-scale manufacturing companies, like furniture manufacturing companies, as they may not have the luxury of buying a large 3D printer. Since the cost of each 3D printer heavily relies on the size of its build volume, desktop 3D printers tend to be one of the more affordable industrial 3D printers [65]. However, most desktop 3D printers use Fused Filament Fabrication (FFF) technology. Therefore, if a manufacturing company wants to use another type of 3D printing technology, a larger industrial 3D printer is necessary [66].

Large-Format 3D Printer. Since typical furniture tends to be much bigger than a desktop 3D printer's maximum build volume, using a larger 3D printer is the straightforward approach that can be used. Large-format 3D printing can create full-scale prototypes, models, and production parts for various applications, including furniture manufacturing. Large-format 3D printers today mean having build volumes beyond the typical dimensions of desktop 3D printers, and some go beyond this dimension which are typically industrial 3D printers with higher cost, complexity, and facility requirements, making them inaccessible for most individuals. That is why many 3D-printed furniture projects were produced through ventures of large companies or artisan pieces [67]. However, there are already attempts to make large-format 3D printing more affordable and accessible. One is by using a pellet extrusion system for most large-format materials extrusion-based 3D printers. Pellet extrusion system enables higher extrusion and faster printing rate than filament extrusion systems, which is crucial for big 3D-printed furniture projects where printing duration increases exponentially with part size. The usage of plastic pellets, it makes easier to combine different plastics to formulate custom polymer blends and colors and allows direct printing of shredded plastics from recycled plastics or failed and unwanted printouts as feedstocks, making it cost-effective. However, these systems struggle with retraction, a feature that filament extruders employ to improve surface finish. To address this problem, some large 3D printers operate with filament and pellet extrusion systems, allowing users to select what is best for their specific application [68].

In recent years, robotic arm 3D printing is increasingly finding its application in large projects, including furniture manufacturing. Unlike conventional 3D printers that move on three axes (X, Y, and Z) [69], the robotic arm 3D printing uses a multi-axis robotic arm to create a much more flexible 3D printer than conventional 3D printers. With the wide range of motion of the robotic arm, it can practically print from any angle, enabling extremely complex design geometries increasing the degree of design freedom, and providing much larger print sizes up to 30 meters or more. Large-format robotic arm 3D printers are less expensive and does not require higher startup investment like conventional large-format 3D printers because most of them are self-build. Since most manufacturing companies already own robotic arms, they can reconfigure them with new tools suitable for 3D printing application. This trend has kept robotic arm 3D printing from becoming mainstream solutions in many manufacturing industries like furniture-making [70], [71].

Hangprinter. Hangprinting is a relatively new technique for furniture 3D printing. It uses a 3D printer called Hangprinter which is an open-source printer designed by Torbjørn Ludvigsen intended to 3D print large objects as cost-effectively as possible. In contrast to conventional 3D printers which print inside enclosures, the Hangprinter is a frameless 3D printer mounted on room's ceiling allowing the maximum build volume as big as the room allows. The Hangprinter has an effector suspended from the ceiling and moves using stationary motors with a system of wires and computer-controlled pulleys anchored to the walls, floor, and ceiling. Most components needed for a Hangprinter can be replicated and printed out by itself, making it the most affordable and accessible way to produce fully 3D-printed furniture [72], [73]. When Hangprinter debuted in mid-2017, there were already a few examples of Hangprinted projects, including coffee tables, chairs, and stools [73]. As reported, other similar large-scale experimental

printers use the Hangprinting technique [74], [75], [76]. Recently, Petsiuk et al. conducted a study that successfully provided a proof-of-concept for a novel, open-source Hangprinter design that allows for recycled plastic waste-based direct extrusion in large expandable printing volumes [77]. However, despite proving that this technique can indeed print furniture, these techniques have significant shortcomings, such as the occurrence of layer shifts and layer adhesion defects, it requires familiarity with 3D printers' construction and operation, and it is so loud during operation [73].

Approaches to Integrate 3D Printing into Furniture

The integration of 3D printing in furniture manufacturing offers manufacturers and designers new methodologies for creating innovative, functional, and aesthetically pleasing furniture pieces. There are three distinct approaches to integrate 3D printing into furniture design, each approach presents unique advantages and challenges that furniture designers must carefully consider.

First approach is having a fully 3D-printed furniture which means that entire furniture piece is produced using 3D printing, often from a single material or a combination of printable materials. This approach offers designers unparalleled creative freedom and production efficiency, enabling rapid manufacturing of complex designs. This method is cost-effective, with custom furniture often priced significantly lower than traditional manufacturing options. However, fully 3D-printed furniture faces challenges such as limited consumer appeal due to its modern aesthetic, material constraints that cannot replicate the qualities of traditional materials like hardwoods, and size limitations imposed by printer build volumes [78], [79].

Next approach is having a furniture with 3D-printed components which refers to furniture pieces where certain parts, like connectors, handles, or decorative elements, are created using 3D printing while other components are made using traditional methods. Instead of printing the entire piece, furniture can be created with traditional materials like wood, metal, or other materials as its base, combined with 3D-printed components such as connectors, handles, or decorative elements [9]. This approach enables highly customized and intricate designs that are difficult to achieve with traditional manufacturing methods [80]. 3D printing offers versatility in materials and allows for the efficient production of unique features like custom joints, textured handles, and detailed embellishments. The benefits include greater design freedom, reduced material waste, and faster prototyping or production [81]. However, challenges include integrating 3D-printed parts with traditional ones, requiring careful attention to material compatibility, structural integrity, and aesthetic consistency. Quality variations between manufacturing methods may create weak points or visual inconsistencies while combining processes can increase production complexity, potentially offsetting cost, and time benefits [82].

The third approach focuses on using 3D printing specifically for joineries and connectors while constructing the main furniture components from traditional materials. This approach only focuses on replacing traditional joints, like mortise-and-tenon joints with 3D-printed connectors that join standard wood or metal parts [83]. This method offers significant practical benefits for

furniture manufacturing. Recent research highlights the advantages of 3D-printed connectors in furniture manufacturing, showing they can match or exceed the mechanical performance of traditional joints. PLA-based connectors produced via Fused Filament Fabrication (FFF) demonstrated superior strength under compression and tensile loads compared to wooden mortise-and-tenon joints. These connectors streamline production by eliminating labor-intensive processes like gluing, enabling easier assembly and disassembly, reducing packaging and transport costs, and allowing for component replacement to extend furniture lifespan. However, material challenges include heterogeneous filament structures and defects that affect mechanical behavior, requiring optimization of connector design and filament deposition methods. Additionally, costs remain relatively high, necessitating further research to improve economic feasibility while maintaining performance [83].

Discussions and Recommendation

Philippines' 3D Printing Furniture Industry

The Philippine furniture industry is projected to have a market value of US\$ 1,715 million by 2033, driven by rising urbanization and an expanding middle class [84]. This growth could create opportunities for innovative manufacturing methods like 3D printing. On the other hand, the Philippine 3D printing market is expected to grow at a Compound Annual Growth Rate (CAGR) of 15.3% from 2025 to 2031, driven by advancements in the healthcare, construction, and manufacturing industry [85]. While this growth is not explicitly focused on furniture, the growth of the furniture industry and 3D printing sectors suggests potential opportunities for innovation and expansion in this area. 3D printing offers the ability to create customized and complex designs, which could appeal to the diverse and evolving needs of the Philippine furniture market.

Whilst 3D printing has revolutionary potential for the Philippine furniture industry, and despite the initiative of the Department of Science and Technology (DOST) to promote 3D printing and advanced manufacturing in the Philippines [86], its adoption encounters significant drawbacks in economic, technical, and cultural contexts due to several challenges. These challenges include the high cost of equipment and materials for large-scale furniture production. The upfront investment in 3D printers capable of producing large furniture pieces is significant, which can deter adoption. Even though there is already a low-cost 3D printer with a smaller build size, a more sophisticated 3D printer can cost at least Php 100,000 or more depending on the build size and type of technology. Aside from the printer itself, its corresponding material cost also varies depending on the quality and type of the 3D printer [87]. Another challenge is the lack of skilled or trained personnel in implementing 3D printing since it requires expertise in design software (e.g., CAD), machine operation, and post-processing techniques, but there are already initiatives to promote 3D printing knowledge and skills [88], [89]. Size limitations pose another challenge since most 3D printers have limited build volumes, restricting the size of furniture pieces that can be printed in one go [90]. Lastly, another challenge is limited material selection for 3D printing since furniture production often requires durable, aesthetic, and versatile materials.

Current 3D printing materials may lack the strength, flexibility, or finish necessary for high-quality furniture [88] Because of these challenges, local manufacturers were accustomed to the high costs, lack of resources, and market competition with traditional artisanship.

However, by learning from international best practices and by selecting the appropriate 3D printing technology and materials, the 3D printer's build volume, and the approach to integrating 3D-printed parts in furniture, the Philippine furniture industry can overcome these challenges. Therefore, the author suggests strategies based on the gathered information tailored to the Philippines' economic status to overcome these challenges. In terms of 3D printing technology, Fused Filament Fabrication (FFF) is the most suitable technology for the Philippines due to its affordability, accessibility, and versatility, making them ideal for small-scale furniture manufacturers [91], [92]. Additionally, pellet extrusion systems within large-format FFF printers allow the use of recycled plastics, which aligns with sustainability goals and reduces material costs. For 3D printing materials, recycled Polymers such as PETG, polypropylene (PP), and polyethylene (PE) are the most suitable for furniture manufacturing in the Philippines, because they are affordable, sustainable, and readily available due to the country's plastic waste problem. But wood-filled filaments can also be used for decorative or artistic furniture since they offer eco-friendly options with aesthetic appeal. With regards to the most suitable 3D printer's build size, it depends on the size of the furniture to be manufactured. The Hangprinter is the most suitable choice for large-scale furniture manufacturing due to its affordability and ability to print objects as large as the room allows without requiring expensive industrial setups. Desktop 3D printers are ideal for smaller modular parts because they are compact, affordable, and widely accessible. Lastly, the most suitable approach in integrating 3D printing in furniture parts for the Philippines is by using 3D-printed joineries and connectors because it is combined with traditional materials, providing a practical solution. This approach minimizes costs while maximizing the mechanical advantages of 3D printing for assembly and disassembly. It also allows manufacturers to use locally available materials while benefiting from innovative designs enabled by 3D printing. These strategies address key challenges such as affordability, accessibility, sustainability, and scalability. By adopting these strategies, the Philippine furniture industry can overcome barriers to entering 3D printing by promoting sustainable and cost-effective practices.

Recently, there have been some local initiatives that adopt 3D printing for furniture manufacturing using these strategies. In 2021, the Bataan Peninsula State University - DR3AM Center led by Prof. John Ryan Dizon through a project funded by the Department of Science and Technology (DOST) – Region III, applies 3D printing to enhance the competitive advantage of the local bamboo and furniture Industry in the Philippines. It is a collaborative project of BPSU-DR3AM Center together with local manufacturers of furniture and bamboo-based products that aimed to innovate traditional furniture making through hybrid manufacturing such as fabrication of component parts that allows designs to be knocked down and assembled thus making the packaging, handling, and quality control more efficient. They used hybrid manufacturing by combining 3D printing with traditional bamboo furniture manufacturing, to increase manufacturing capabilities and add value to bamboo-based products. They were able to create

3D-printed connectors/joints for bamboo-based furniture products and other bamboo-based products. Hybrid manufacturing proposes a practical solution to the high equipment and material costs hindering 3D printing adoption in the Philippine furniture industry.

Summary

This paper discusses the applications of 3D printing in furniture manufacturing and provides insights into how it can be adopted in the Philippines' furniture industry. It addresses challenges and proposes strategies for successful integration. Three key aspects are covered: 3D printing technologies, and 3D printing materials, build volume of 3D printers, and approaches to incorporating 3D-printed parts into furniture designs. The paper highlights various 3D printing technologies and materials already used in the international furniture industry. The paper also examines three types of 3D printers based on build volume, as well as discusses three approaches to incorporating 3D printing in furniture design. By leveraging these technologies, materials, build volumes, and approaches, the Philippines can adopt innovative solutions tailored to its economic conditions. Affordable technologies like FFF/FDM paired with recycled materials can promote sustainable practices while addressing cost constraints. Handprinting offers a scalable option for large-scale furniture production. Desktop 3D printers provide a practical entry point into advanced manufacturing without requiring heavy investments by combining traditional materials with 3D-printed connectors. These strategies can help overcome challenges and position the Philippine furniture industry for growth in the global market.

3D printing can significantly change products and the way they are manufactured. As additive manufacturing technology continues to advance, the process, the material, the 3D printer, and approaches will likely become increasingly sophisticated, offering furniture designers even greater opportunities to innovate while addressing current limitations. The future of furniture design lies in the strategic application of these 3D printing methodologies to create pieces that are not only beautiful and functional but also sustainable and economically viable.

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